A Colorless Remote Antenna Unit for Bidirectional Photonic Antenna Remoting

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***Abstract*—A colorless (wavelength-independent) remote antenna unit (RAU) for bidirectional photonic antenna remoting is proposed and demonstrated, which is based on a reflective semiconductor optical amplifier electroabsorption modulator (SOA-EAM). Due to the gain saturation effect in the semiconductor optical amplifier (SOA) of the reflective SOA-EAM, the microwave signal carried by the downlink optical signal is received and effectively erased. Then, the electroabsorption modulator (EAM) converts the uplink RF signal to an optical signal, which is reflected back to the center office (CO) by the high-reflection coated facet of the device to provide the uplink service. No signal downconversion is needed since the modulation bandwidth of the EAM can reach tens of GHz. A proof-of-concept experiment is carried out. The RAU performs well in a bidirectional radio over fiber (ROF) system for providing 500 Mb/s wireless services centered at 2 GHz.**

***Index Terms*—Antenna, microwave photonics, radio over fiber.**

I. Introduction

PHOTONIC antenna remoting has been considered as a promising technology in radars, radioastronomy systems and wireless communication networks [1]–[5]. By inserting a wideband and low-loss fiber-optic analog link [3]–[6] into the microwave system, the complex, power consumptive, and costly signal processing module can be moved from the antenna unit to a center office (CO). Meanwhile, the antenna unit has to include some opto-electronic components. Previously, only an analog optical transmitter was incorporated into the remote antenna unit (RAU), since the photonic antenna remoting application was assumed to be receive-only [1]–[6]. However, for practical applications, both transmit and receive functions should be supported [7], which would increase significantly the complexity and cost of the RAU. In addition, many applications, such as array radars and distributed antenna systems, have many RAUs connected to a CO. To differentiate each RAU, wavelength-division multiplexing (WDM) is an efficient and mostly-used method, but this would require expensive wavelength-specific or wavelength-tunable optical sources. To reduce the cost, wavelength-independent, i.e., colorless RAU is highly desirable [8]–[11].

As early as 1996, an electroabsorption modulator (EAM) was used to implement a simple and colorless RAU, where the EAM acts simultaneously as a photodetector (PD) and a modulator [12]. However, the downlink and uplink microwave signal must be in different frequency bands to avoid interference. In [13], a wavelength-independent RAU was proposed and demonstrated based on a reflective semiconductor optical amplifier (RSOA). Error-free operation was achieved for both 1.25 Gb/s uplink and downlink wireless services. The key problem with this approach is that the RF frequency downconversion is required due to the limited frequency response of the RSOA, which not only increases the cost of the RAU significantly, but also makes the RAU not transparent to other wireless services or frequency-agile applications.

In this letter, a colorless RAU for a bidirectional photonic antenna remoting system is proposed and demonstrated. The key device in the RAU is the reflective SOA-EAM, which performs simultaneously the downlink information erasing, optical amplification and uplink signal modulation without the need for RF frequency downconversion. A 2 GHz 500 Mb/s bidirectional ROF system is established based on the RAU. The clear eye diagrams and electrical spectra of the signals received at the RAU and CO demonstrate the feasibility of the proposed scheme.

II. Principle

Fig. 1 illustrates the schematic diagram of an ROF antenna remoting system incorporating the proposed colorless RAU. The RAU consists of an optical coupler, a reflective SOA-EAM, a PD, two electrical amplifiers, an electrical circulator, and an antenna. The optical downlink signal introduced to the RAU is split into two parts by the optical coupler. One portion of the signal is directly detected by the PD, which is then amplified and distributed to free space by the antenna for downlink services. The other part of the signal is sent to the reflective SOA-EAM. The SOA in the reflective SOA-EAM is properly biased and operated in the gain saturation region. As shown in Fig. 2, due to the gain saturation, the output optical power from the SOA can reach a quasi-constant level when the input optical power is sufficiently large, and this can be used to erase the intensity modulated information in the optical signal [14], [15]. The clean optical signal is then modulated at the EAM by the uplink signal from the antenna, which is reflected back to the CO by the high-reflection coated facet of the reflective SOA-EAM for uplink services. Because there is no wavelength-dependent device in the scheme, the proposed RAU is colorless. The bandwidth of the EAM can reach tens of GHz [16], so the wireless

Manuscript received April 01, 2013; revised November 07, 2013; accepted December 01, 2013. Date of publication January 16, 2014; date of current version April 04, 2014. This work was supported in part by the National Basic Research Program of China(2012CB315705), the National Natural Science Foundation of China(61107063, 61201048), the Natural Science Foundation of Jiangsu Province(BK2012031, BK2012381), the Project sponsored by SRF for ROCS, SEM, the Jiangsu Provincial Program for High-level Talents in Six Areas (DZXX-034), and a Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

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Digital Object Identifier 10.1109/LMWC.2013.2295232

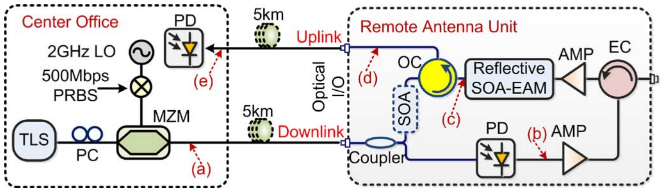

Fig. 1. Experimental setup for evaluating the proposed colorless RAU. TLS: tunable laser source; PC: polarization controller; MZM: Mach-Zehnder modulator; LO: local oscillator; PRBS: pseudorandom bit sequence; OC: optical circulator; SOA-EAM: semiconductor optical amplifier electroabsorption modulator; AMP: amplifier; EC: electrical circulator; PD: photodetector. The letters (a)–(e) indicate points in the system at which Fig. 4 shows measured spectra and eye diagrams.

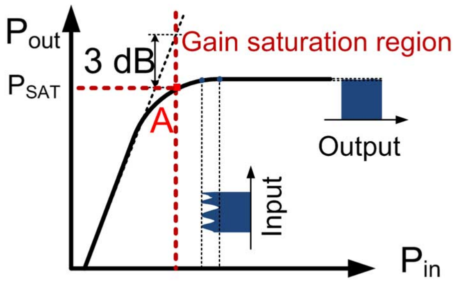

Fig. 2. Gain saturation in a SOA for downlink information erasing. P_{SAT}: saturation power.

signal can directly modulate on the uplink optical signal without any pre-downconversion. This not only saves an RF mixer and a frequency-locked local oscillator, but also makes the RAU transparent to other wireless services, which is of great importance for cognitive wireless systems or frequency-agile systems. In addition, all the devices in the RAU including the reflective SOA-EAM are almost polarization insensitive, so no adaptive polarization controlling is required.

III. Experimental Demonstration

To investigate the performance of the proposed RAU, an experiment is performed based on the configuration shown in Fig. 1. A continuous-wave light from a tunable laser source (TLS, SANTUR TL-2020-C) with the power of 10 dBm is modulated by a 2 GHz RF signal at a Mach-Zehnder modulator (MZM, Fujitsu FTM7921ER). The half-wave voltage of the MZM is 4 V, and the RF signal is generated by mixing a 2 GHz RF carrier (Agilent E8257D) with a 500 Mb/s pseudo-random bit sequence (PRBS) from a pulse pattern generator (PPG, Anritsu MP1763C) with a word length of $2^{31} - 1$. The generated optical signal is transmitted through a 5 km single-mode fiber (SMF) and then introduced to the proposed RAU. The key device in the RAU is the reflective SOA-EAM (CIP Inc., SOA-EAM-R-10-C-7S-FCA), which performs simultaneously the downlink information erasing, optical amplification and uplink signal modulation. The SOA in the reflective SOA-EAM is biased at 100 mA and the EAM is biased at -1.4 V, which yields a small-signal gain of about 18 dB and a saturation output power of about 8 dBm. The RF signal to the EAM is obtained by introducing a long time delay to the downlink RF signal so that the uplink and downlink signals are irrelevant. The uplink optical signal is then reflected back to the CO via an optical circulator and another 5 km SMF.

The key issue to implementing the colorless RAU is the ability of the reflective SOA-EAM to erase the downlink

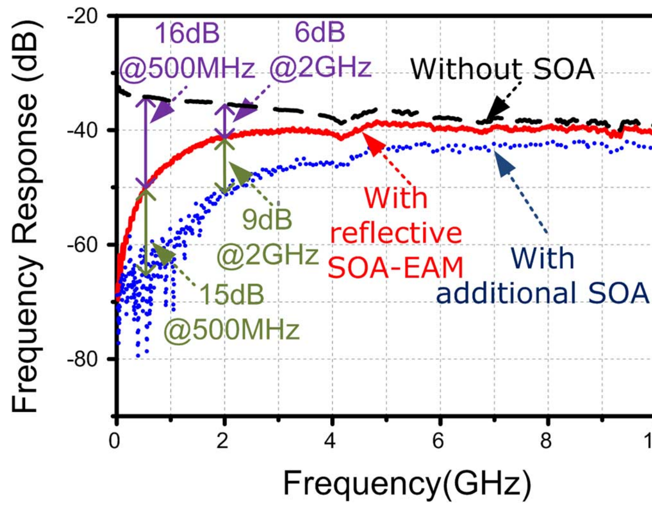

Fig. 3. Frequency response curves of a RF link without the SOA (dashed line), with the reflective SOA-EAM (solid line), or with an additional SOA (dotted line).

information. Therefore, the gain saturation in the reflective SOA-EAM is evaluated by a vector network analyzer (VNA, Agilent N5230A). To do this, the output port of the VNA is connected to an MZM. The intensity-modulated signal from the MZM is sent to the reflective SOA-EAM, and then reflected to a PD through an optical circulator. The output port of the PD is connected to the input port of the VNA. The optical power to the PD is fixed at 3.3 dBm. Fig. 3 shows the frequency response curves obtained by the VNA. As can be seen, the gain saturation of the reflective SOA-EAM effectively suppresses the information at the low frequency regime, but it has very small impact on the high-frequency components. For instance, when the frequency is 500 MHz, the RF power is reduced by 16 dB, but the RF power reduction is only 6 dB when the frequency is increased to 2 GHz, which is insufficient for wavelength reuse in a RoF system. To overcome the problem, we insert another SOA (Kamelian ltd., SOA-NL-L1-C-FA) with a bias current of 120 mA to the system. As shown in the dotted line in Fig. 3, the RF power reduction at 2 GHz is increased to 15 dB, so the suppression of the RF signal is greatly enhanced. It should be noted that the maximum input optical power of the reflective SOA-EAM is only 4.4 dBm. If the SOA-EAM is designed to tolerate a larger input power or to have a longer active region, the gain saturation could be increased and the additional SOA would not be needed.

Fig. 4 shows the electrical spectra and the eye diagrams of the 2 GHz RF signal with a 500 Mb/s PRBS at different points in the bidirectional ROF system shown in Fig. 1. Fig. 4(a) shows the downlink wireless signal for transmission and Fig. 4(b) shows the case when the signal is received at the RAU after the 5 km SMF transmission. Only power attenuation is observed. When the downlink signal is sent to the reflective SOA-EAM, the information is suppressed by more than 15 dB. As shown in Fig. 4(c), the eye diagram is closed, showing that the downlink information is effectively erased. Then the uplink signal is introduced to the EAM of the reflective SOA-EAM. Fig. 4(d) illustrates the electrical spectrum and the eye diagram of the uplink optical signal at the output of the reflective SOA-EAM. A widely-opened eye diagram is observed again. The uplink signal

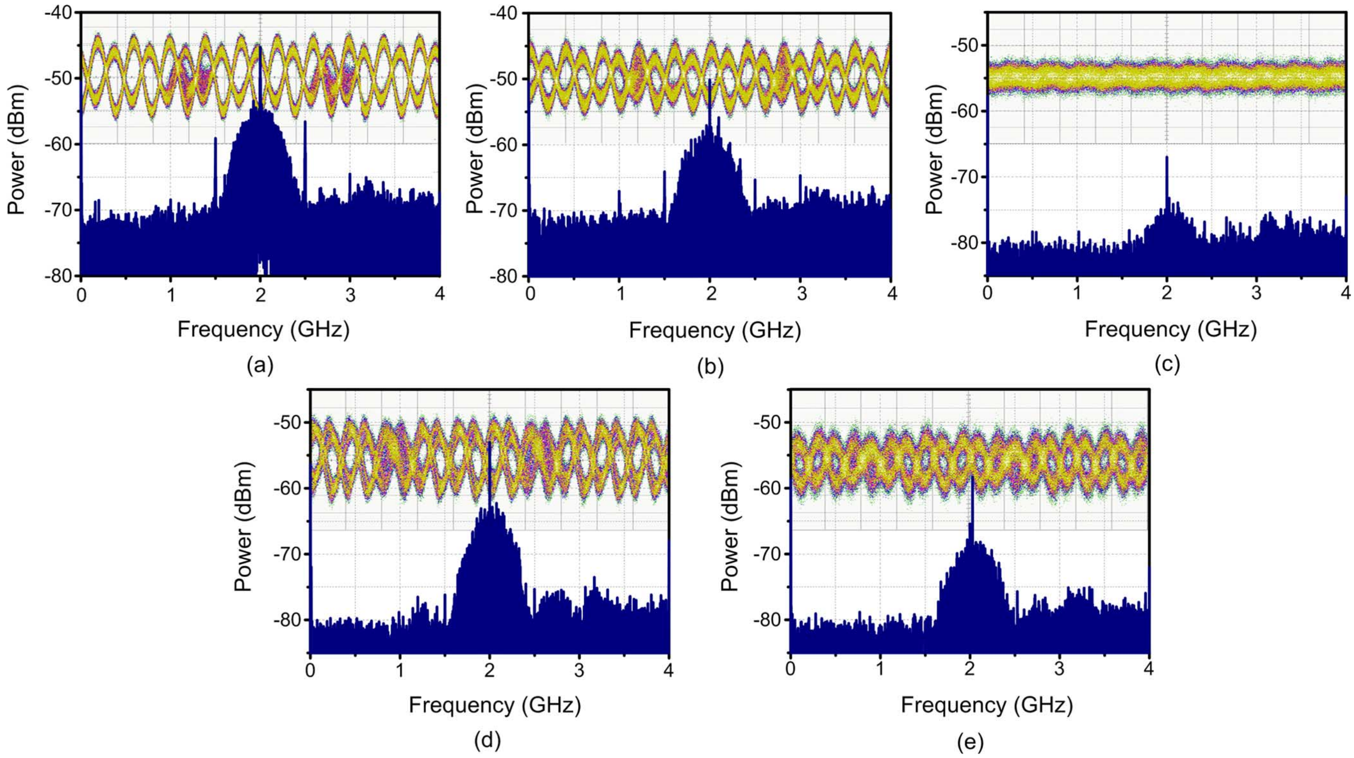

Fig. 4. Spectra and eye diagrams at these points in the system shown in Fig. 1: (a) the transmitted signal, (b) the received signal, (c) the performance after erasure, (d) the remodulation performance, and (e) the transmitting via 5 km single-mode fiber.

is transmitted through the 5 km SMF to the CO. The received signal is shown in Fig. 4(e). Although the signal is attenuated due to the fiber loss, the eye diagram is still clear, showing the effectiveness of the wavelength reuse in the RAU.

IV. Conclusion

A colorless RAU based on a reflective SOA-EAM device for the bidirectional photonic antenna remoting system was proposed and demonstrated. A 2 GHz 500 Mb/s bidirectional RoF system was constructed and tested based on the RAU. More than 15 dB suppression of the downlink RF signal is obtained with the assistance of a second SOA. The uplink optical signal reflected by the reflective SOA-EAM to the CO has a widely-opened eye diagram. The RAU is simple and compact, which can find applications in fiber-connected distributed antenna systems, radars and radioastronomy arrays.

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